# PARAMETER STUDY FOR FEL PROJECT AT INFLPR

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*Abstract*

The RO FEL proposal is the result of a research contract financed in Romania for to extend the applications of electron accelerators - 7 MeV linac, 11.5 MeV microtron, 31 MeV betatron and 40 MeV medical betatron – built in the National Institute for Lasers, Plasma and Radiation Physics (INFLPR), Romania. This paper is a presentation of the concept and system parameters for Linac-based Free-Electron Laser Project at INFLPR (RO FEL). The project has considered the recent advances of technologies in the domain of accelerators, lasers, undulators and seeded operation with HGHG. The Project proposal has also considered the frequency domains from Infra-Red to Hard X-rays, dividing it in 5 spectral domains, following that the scientific community in Romania should establish which domain still stay and which is the first to start, function of the application. By now, our local experience in building and application of charged particle accelerators and the use of laser systems have been considered for accomplishing a FEL which may generate coherent radiation in the Infra-Red and Ultraviolet/Vacuum – ultraviolet wavelength, in the first stage, the final milestone being to obtain coherent ionizing radiations in the HXR range.

## INTRODUCTION

Since the Theodore Maiman's demonstration of the first laser on 16 May 1960, about 50 years ago, scientists have been participating in the achievement of several programs for the construction and application of the coherent radiation generated by FEL facilities.

The 1.5 eV energy of a laser photon has been used to produce X radiations of 1 keV order and today there are programs in progress for to obtain indirect coherent ionizing radiation sources ( photons with energy > 5keV) by means of FELs [1].

Among such FEL sources it is woth mentioning : the Linac Coherent Source (LCLS), a SASE, 0.15 nm x-ray FEL facility under construction at SLAC, European X FEL DESY, 0.1 nm, and SCSS X FEL Spring 8, 0.1nm.

As regards the duration of coherent radiation pulses to be generated by FEL, we witness the process from femtoseconds to attoseconds (152 ats representing a the rotation period of an electron on the first Bohr orbit at v = 2. 1877 x $10^6$ m/s and $r_B$ = 0.0529 nm) [2].

This paper is a presentation of a general concept of the proposed project RO FEL and its system parameters in the infra-red (IR) spectral range – hard x-ray (HXR), devided into 5 spectral sub-ranges, following that the scientists in Romania should determine which of them remain and which may be the spectral range to start with. The paper also presents the general options, operational specified in the project and the initial operational parameters. Talks are still developing for finalizing the Conceptual Design Report.

## FEL GENERAL OPTIONS

The X-ray free Electron Laser (XFEL) is perceived as a fourth generation synchrotron light source and therefore the RO FEL project was proposed as final milestone.

Today, FEL facility may be constructed in one of the 3 alternatives: Linac-based FEL, Storage ring (SR) FEL and Energy Recovery Linac (ERL) FEL. To select one of the alternatives, we have to state a qualification of FEL radiation parameters as: excellent (ex), good (g) and zero (no). Which are written down in the sequence: FEL/ERL/SR, and which are to have the following characteristics: temporal coherence: ex/no/no, spatial coherence: ex/ex/no, ultrashort pulses: ex/g/no, synchronization: ex/no/no, average flux: ex/g/g; average brightness: ex/ex/g, source bandwith: ex/g/g, tenability: ex/ex/ex, pulse repetition rate: g/ex/ex, and beam stability: g/g/ex. Besides, FEL represents an advanced step as to the synchrotron radiation because with FEL the process of radiation is benefiting from the multiple coherence while with the synchrotron radiation is in-coherently emitted independently from the electrons which generate it.

Analyzing the above presented proposals for RO FEL, we have selected the solution of the single pass linac-based FEL that can generate the coherent radiation in the range of IR-HXR and can be achieved at national level.

Besides the above, linac allows the production of high currents of kA order and of a normalized emittance of the order $10^6$ m-rad. In the XSASE FEL range, linac shows the advantage of a low emittance $\varepsilon_x = 0.3 \times 10^{10}$ m-rad (15 GeV, 15 kA, 200 fs) while the emittance of the electron beam at a storage ring, is $10^9$ m-rad (10 ps, 1 nC).

Among the types of injectors for RO FEL, the photoelectric injector has been selected because it has a low emittance and allows the generation of short pulses.

When selecting the wavelengths, one considered the progress made with conventional lasers (P =$10^{15}$ W, $\mathcal{E}$ = ħω = 1.5 eV, $I_0\lambda_0^2 > 1.38 \times 10^{18}$ Wμm$^2$cm$^{-2}$, τ < 1 ps) which

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permitted the operation of lasers in the relativistic range ($eE\lambda_0 > 3.20$ MeV, $a_0 = 8.5x10^{-10}\lambda_0$ [μm]$I_0^{1/2}$ [W/cm$^2$]) and high electric fields E(TV/m) = 3.2 $a_0/\lambda_0$[μm] where ℰ is the photon energy, E, ω, $\lambda_0$ and $I_0$ are the electric field intensity, frequency, wavelength and laser radiation intensity, e and m are the electric charge and rest mass of the electron, and c is the light speed. Also, progress made in the domain of laser-plasma interaction ($n_0 = 10^{18}$cm$^{-3}$, $\lambda_p = 2\pi c/\omega_p$, $E_p$ = 96 x $n_0^{1/2}$ [cm$^{-3}$] = 96GeV/m) for short distances of several cms) and in the domain of electron – plasma interaction (50 GV/m along 1 m distance) [3].

## FEL OPERATIONAL OPTIONS

To satisfy the requirements of potential users, RO FEL project proposal is providing 5 research labs structured on 5 spectral domains, namely: Infrared (IR: 1000 μm > λ > 0.77 μm), Ultraviolet /Vacuum-ultraviolet (UV/VUV: 390 nm / 180 > λ > 50nm), Extrem-ultraviolet (XUV: 50nm > λ > 5 nm), Soft x-ray (SXR: 5nm > λ > 0.25nm) and Hard x-ray (HXR: λ < 0.25nm – ionizing radiation range). The first 4 shall be referred to as "spectral labs" and the fifth one shall be called: "ionizing radiation lab".

The Concept scheme for RO FEL, presented in Fig. 1 is also specifying a further experimental lab for the research

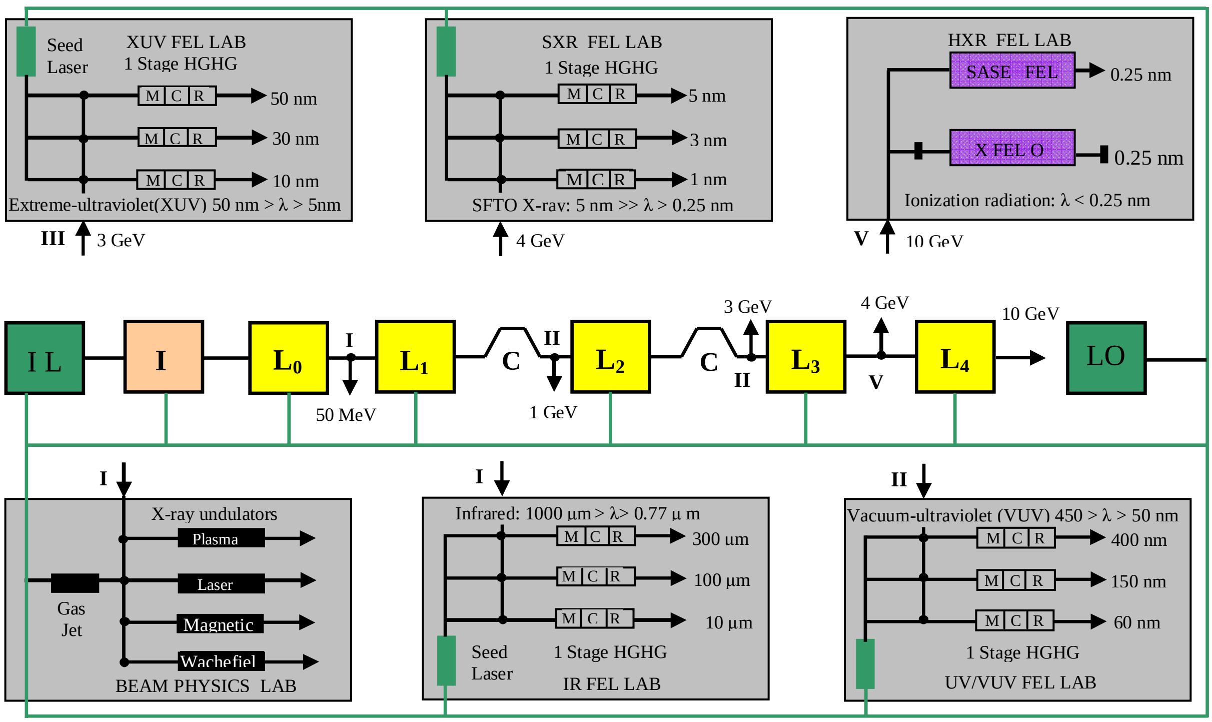


Figure1: Concept for RO FEL Facility. (IL-Injector Laser, I-Injector, L-Linac, C-Compressor, LO-Oscillator Laser,)

of beam physics, dedicated to the research of electron acceleration in plasma, of high-order harmonics generation (HHG) in the plasma jet and of x-ray generation, using undulators of type, magnetic, lasers and plasmas. This lab is aimed to disseminate the results of the research at national level, in universities and institutes.

As regards the configuration of a FEL source, it may be one of the following types: first, a Oscillator type (O) which employs the optical resonator for to provide a high level of spatial and temporal coherence and which offers many benefits in wavelength regimes where suitable mirror exist; secondly, it may be the type of Self - Amplified Spontaneous Emission **(**SASE) in which the spontaneous radiation emitted by quivering electrons at the beginning of an long magnetic undulator is subsequently amplified because the electrons pass through the magnetic structure; and thirdly, it may be of the HGHG type (High Gain Harmonic Generation) which is a single-pass FEL in which a laser seed induces an energy modulation in the electron beam in the first undulator called Modulator. This energy modulation is converted into a coherent spatial density modulation in the Dispersion Magnet, and radiation at the n-th harmonic of the seed laser wavelength is generated and amplified to saturation in the second undulator called: Radiator [4].

For the first 5 spectral ranges within the 5 labs defined in Fig.1, in RO FEL Project the coherent radiation is obtained by HGHG method [5], and in the last lab, (the one dedicated to indirect ionizing radiation generation-HXR) SASE method has been selected [6] and recently, there are proposals for the option with Oscillator [7].

All data mentioned above regarding HGHG method, are calculated by the relations:

$$\lambda_0 = \lambda_m = \frac{\lambda_u}{2\gamma^2}(1+\frac{K^2}{2}) \qquad 1)$$

$$\lambda_r = \frac{\lambda_m}{n} = \frac{\lambda_u}{2\gamma^2}(1+\frac{K^2}{2}) \qquad 1")$$

where n is the harmonic number, $\gamma$ is Lorentz factor and $K \equiv e \cdot B\ \lambda_0 / 2\pi mc = 0.934\ B(T)\ \lambda_0(cm)$ is the undulator intensity.

Table 1: Review of preliminary parameters for RO FEL

| Parameter | Value |
|---|---|
| Electron beam | |
| Nominal beam energy, $E$ | 0.75- 1 GeV |
| Normalized beam emittance, $\epsilon_{x,y}$ | 1 - 2 mm-mrad |
| Bunch length, $l_b$ | 400-50 fs |
| Bunch charged, $Q$ | 0.1-1 nC |
| Beam size (rms), $\sigma_{x,y}$ | 250-300 µm |
| Peak beam current, $\hat{I}$ | 1kA |
| Seeded Free Electron Laser | |
| Seed laser wavelength, $\lambda_s$ | 200-250 nm |
| Modulator peak field, $\hat{B}_y^{mod}$ | 1T |
| Modulator periodicity, $\lambda_{mod}$ | 5.6-6 cm |
| Modulator strength, $K_{mod}$ | 5.23-5.6 |
| Radiation peak field (circ.pol.), $\hat{B}_{x,y}^{rad}$ | 0.7T |
| Radiation periodicity, $\lambda_{rad}$ | 4.4-4.7 cm |
| Radiation strength, $K_{rad}$ | 3.28-3.5 |
| Emitted wavelength (3rd harmonic) $\lambda_e$ | 67-83 nm |
| Emitted peak power, $\hat{P}_e$ | 1-2 GW |

For both SASE and HGHG configurations, FEL gain length-$L_G$, saturated output power – $P_s$, and acceptable energy spread scale, $\sigma_E/E$, with FEL parameter – $\rho(I_b, \varepsilon.K, \lambda_u) \approx 1\text{-}2\text{x}10^{-3}$, we used:

$$L_G = \frac{\lambda_u}{4\sqrt{3}\pi\rho} \qquad 2)$$

$$P_s \approx \rho I_b \frac{E_b}{e}; \quad \frac{\sigma_E}{E} < \rho \qquad 2')$$

For a good output properties, we choose I = 1kA (1nC/ps), $\sigma_E/E < 0.025\%$, $P_s$ = 1-2GW and $L_u$ = 30-80m.

These are the followings: 1. development of RF photocathode guns; 2. preservation of electron beam qualities in the compression and acceleration processes, and 3. the development of the magnetic undulators accuracy. For RO FEL a photoelectric injector was proposed [8]. With the recent benefits of the RF photocathode gun, with the emittance correction techniques, linacs have become a promising option for SASE order for x-ray wavelength.

## CONCLUSIONS

In conclusion, Table 1 is a summing-up of the system parameters for the electron beam, modulator and radiator, obtained by the two methods – HGHG and SASE – the first one being applicable to spectral ranges from IR FEL to SXR FEL and the second, for SASE FEL, the spectral range of ionizing radiation.

According to the conceptual design report, the first stage of the project shall be finalized by the accomplishment and commissioning of IR FEL Lab module along with the construction of the lab dedicated to the neutral and/or charged particle beam physics. The latter is aimed to study the x ray radiation sources at lab level, using magnetic undulators, plasma, laser and electron accelerators in plasma.

Experience gained along the finalization of the two labs, will be applied in the comming stages of RO FEL development process.

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